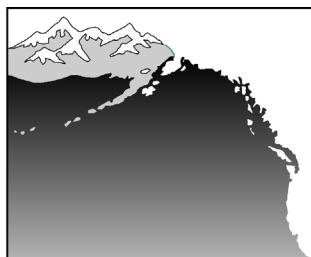# Olympic Sculpture Park: Results from Pre-construction Biological Monitoring of Shoreline Habitats

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Executive Summary

Part of the Seattle Art Museum's Olympic Sculpture Park encompasses habitat along an urbanized portion of marine shoreline. In order to provide benefits for juvenile salmon and other biota, newly constructed habitat within the park is designed to remove or modify seawall and rip-rap armoring to provide riparian and intertidal biological functions. This will involve restoring and maintaining riparian vegetation and creating shallow intertidal habitat that could provide food and refugia for juvenile salmon and other fish. In order to provide pre-construction baseline biological monitoring that will be helpful in measuring the success of the constructed habitat, we conducted fish and invertebrate sampling at the Olympic Sculpture Park site in spring-summer 2005. We used a paired-sample design, each sample pair consisting of the stretch of shoreline that is to be modified and an adjacent stretch of the same habitat that will not be modified, for a total of four sampling locations.

We conducted the following sampling:

- Fish were sampled by snorkel surveys throughout the period of juvenile salmon outmigration through intertidal habitats (12 dates total). Surveys consisted of 75 m transects: at high tide, each of the four stretches of shoreline was sampled at a shallow water depth (just off shore) and deep water depth (10 m from shore) transect. This was repeated at low tide. Observations included fish identification, sizes, behavior, and position in the water column.
- On five dates, epibenthic samples of juvenile salmon prey invertebrates living on the seawall and rip-rap were taken with a diver-operated suction pump at the 0-+1' tidal elevation.
- On seven dates, terrestrial/riparian insects were sampled using traps consisting of plastic containers containing a small amount of soapy water.
- On days that terrestrial/riparian insects were sampled, drift insects on the water's surface were qualitatively sampled with a single diver-deployed neuston net tow.

Shiner perch were much more abundant than any other fish, especially in deeper transects. Juvenile salmon were common and relatively abundant in shallow water at the Olympic Sculpture Park site. This suggests that these fish will have the opportunity to utilize the shallow water habitats that will be incorporated in the park construction. The shoreline stretches that will undergo habitat enhancement already appear to have higher fish abundances than the reference sites, and this should be taken into account in future post-construction monitoring. The reason may be that the restoration sites occur in areas of slight indentations in the shoreline, and this may cause fish to aggregate there. Potential fish predators of juvenile salmon were rare at all sites.

Species composition and densities of epibenthic invertebrates living on the seawall and rip-rap substrates were similar among the sampling sites. A gammarid amphipod crustacean, *Paracalliopiella pratti,* and various barnacle life history stages made up more than 75% of invertebrate numbers at each site. The two rip-rap sites had more barnacle nauplii than the seawall sites, and the seawall reference site had more *P. pratti* than the

restoration site. The rip-rap sites had greater taxa richness than the seawall sites. The amphipods were probably associated with algae produced in the lower intertidal at the seawall and rip-rap habitats, and the barnacles were clearly associated with and abundant on the sampled substrata. The neuston samples also contained epibenthic invertebrates, which may have been suspended in the water column by wave action at the face of the seawall and rip-rap.

Species composition of insects from fallout traps was similar among the seawall and rip-rap sites, consisting mainly of dipteran flies, springtails, and mites. Densities were higher at the two restoration sites as compared to the reference sites. The backshore riparian site had the highest total densities and taxa richness, and differed from the other sites in having fewer dipterans and more springtails and mites. Neuston samples had an insect assemblage composition similar to the fallout traps, but also contained some aquatic invertebrates that were sampled in the epibenthic sampling, such as the amphipod *Paracalliopiella pratti* and harpacticoid copepods. This illustrates that these invertebrates are being made available both in and floating on the water column as potential juvenile salmonid prey items. The high insect numbers and diversity at the backshore riparian site suggests that they are associated with vegetation, and plantings of vegetation associated with the Sculpture Park will probably increase input of insects into the nearshore aquatic environment.

The pre-construction biological monitoring of shoreline habitats reported in this current study are necessary to document baseline conditions before construction and restoration of the site; any conclusions regarding the success of the restoration will not be known until similar post-construction monitoring is completed. We recommend periodic post-construction monitoring, using the paired-sample design and identical methodology, to assess the ecological development of the Olympic Sculpture Park site. Additional sampling methods to be considered in post-construction monitoring include:

- Presence and behavior of potential juvenile salmon predators.
- Capture of juvenile salmon using enclosure nets, in order to obtain site-specific densities and food habits.
- Invertebrate sampling tailored to the new lower-gradient habitats (e.g., cores).
- Quantitative neuston sampling (i.e., transects of standard length).

OLYMPIC SCULPTURE PARK: RESULTS FROM PRE-CONSTRUCTION BIOLOGICAL MONITORING OF SHORELINE HABITATS

Introduction

The Seattle Art Museum's Olympic Sculpture Park will transform an 8.5 acre undeveloped waterfront property and a former industrial site in Elliot Bay into a new open green space for art using native vegetation. Part of the Museum's plan is to develop the shoreline at the project site in a way that provides beneficial habitat functions for wildlife, including threatened Chinook salmon. Juvenile Chinook and other salmonids use the Seattle urban nearshore of Puget Sound including Elliot Bay for rearing and migration (Toft et al. 2004), with the nearby Green/Duwamish Waterway being the closest source for both wild and hatchery juvenile salmonids. Restoration is planned to both enhance shallow water habitat and increase availability of juvenile Chinook prey items, such as insects available on the waters surface and epibenthic crustaceans available on intertidal substrates (Simenstad et al. 1982, Brennan et al. 2004). Monitoring biota at newly constructed or restored habitat provides information to help determine how successful the site is in providing functional habitat. An important component of this biological monitoring is sampling the site before construction in order to document pre-existing baseline conditions. This pre-construction monitoring helps to better measure post-construction benefits associated with the new habitat. Although construction of the upland part of the Olympic Sculpture Park started in early 2005, the shoreline was not modified until fall 2005. This provided one field season, spring-summer 2005, in which to collect pre-construction data. We designed a monitoring plan focused on providing a baseline dataset of pre-construction habitat conditions, emphasizing juvenile salmonid functions of the site. In this report we describe the results of the pre-construction biological monitoring along the shoreline associated with the Olympic Sculpture Park.

The overall ecological objectives of habitat enhancement at the Olympic Sculpture Park are to (1) restore and maintain riparian vegetation to enhance juvenile salmonid refuge functions and insect prey production, and (2) create shallow intertidal habitat to improve rearing opportunities for juvenile salmonids. Currently, the shoreline is retained with seawall and rip-rap with minimal upland riparian vegetation, which severely truncates any available intertidal habitat and access to riparian habitat resources. Recent research in Sydney Harbor, Australia, has shown that seawall fauna can be much different than nearby sloping shores, and seawalls have fewer mobile species compared to natural rocky shores (Chapman 2003, Chapman and Bulleri 2003). Habitat enhancement of the Olympic Sculpture Park shoreline is designed to provide improved conditions for native biota.

There are two shoreline locations that will be effected by construction (Figs. 1,2). At one location, the existing 7000' seawall will remain in place, but the seaward slope will be modified to be low gradient on the northernmost 700', or roughly 10% of the entire seawall. A sloping intertidal area will also be created on the inside edge of the end of the seawall. At the other location, part of the adjacent rip-rap to the north of the seawall will

be removed, with creation of a pocket embayment consisting of a low gradient sand/gravel beach, saltwater marshes and rocky tidepools. Henceforth, we refer to these as the "restoration" sites. In spring-summer 2005 we conducted paired sampling at each of the two planned restoration types: each sample pair consisted of the stretch of shoreline that is to be modified and an adjacent stretch of the same habitat that will not be modified, for a total of four sampling locations (Figs. 1, 2). In the pre-construction monitoring, these sites were contiguous, forming effectively one seawall and one rip-rap site. In future monitoring after construction the sites will consist of (1) the seawall section with modified slope and enclosed intertidal area paired with an adjacent section of unmodified seawall, and (2) the pocket embayment with rip-rap removed, paired with rip-rap outside the embayment that will not be modified by construction. This will enable us to assess the affects of the constructed habitat. If funding allows, regular post-construction monitoring will be conducted (e.g. 1, 3, 5 years after construction), in order to assess ecological development of the site.

Three biological attributes were monitored: (1) presence at the site of juvenile salmonids and other fish, (2) aquatic epibenthic invertebrate fish prey, such as crustaceans and polychaete worms, that live on the substrate of the seawall and rip-rap, and (3) input of terrestrial insects from surrounding vegetation. Data from this pre-construction monitoring, when combined with future post-construction monitoring, will allow us to test the following hypothesis: ***Restoration sites along seawall and rip-rap provide improved habitats for juvenile Chinook salmon and other fish, as measured by invertebrate and fish assemblages.***

Material and Methods

Fish Sampling
Sampling spanned the peak juvenile salmonid outmigration period, beginning with chum salmon in April and ending with Chinook and coho salmon in June and July. Fish were surveyed every week, coinciding with both spring tides (high tidal ranges coinciding with the new and full phases of the moon) and neap tides (low tidal ranges coinciding with the first and last quarter phases of the moon).

Presence and behavior of juvenile salmonids and other fish were monitored using snorkel surveys from 15 April to 13 July. Each transect was 75-m in length. Sixteen transects were sampled on each sampling date. At high tide, each of the four stretches of shoreline was sampled at a shallow and deep water depth transect (just off shore and 10 m from shore; Fig. 3). This was repeated at low tide. This range of data was collected in order to encompass post-construction conditions, which will change beach gradients and corresponding water depth/distance from shore ratios. Successful transects were dependent on sufficient water clarity for underwater visibility, coinciding to horizontal secchi-disk measurements exceeding 2.5-m. Two dates were not sampled because of water conditions: 20 May due to heavy rains and proximity of the combined sewer overflow, and 13 July due to oil on the water.

The following data were collected during snorkel transects:

- Fish identification and number. Numbers of fish were standardized by transect length and water visibility: fish number/[length (m) x horizontal secchi (m)].
- Approximate fish lengths (2.5-cm increments).
- Water column position of fish (surface, mid-water, bottom).
- Fish behavior (schooling, swam away, unaffected, fleeing, feeding).
- Water depth of shallow and deep transects.
- Horizontal secchi readings of underwater visibility for each snorkel surveyor.
- Salinity and temperature of water surface and bottom.

Epibenthic Invertebrates
Epibenthic invertebrates were sampled using an epibenthic pump (16 cm diameter, 106-µm mesh size) deployed at 0.5-m depth while snorkeling (Fig. 4). This device suctions invertebrates from the surface layer of the benthos, in this case either the surface of the seawall or rip-rap. The pump was operated by hand, using 20 pumps for each sample. At each site, we collected seven replicate samples at the 0 to +1' MLLW tidal elevation at random points along the same 75-m transect that was used for the snorkel surveys. The substrate was covered mainly by the barnacle *Balanus glandula*, with some attached algae and open space. The samples were fixed in 10% buffered formalin in the field, and returned to the laboratory for identification of the collected invertebrates. Juvenile salmon prey taxa were usually identified to genus and species level, and other taxa to higher taxonomic levels.

Terrestrial Insects
Shoreline modifications and heavy public use of the site presented a challenge for sampling terrestrial insects using traps. Fallout traps (plastic storage bins 40 x 25 cm) were placed at random points along a 75-m transect parallel to the shore at the high intertidal of each site (Fig. 5). One transect was also sampled in the backshore riparian zone (Fig. 1). The bottom of the traps was covered with a mild soap solution and they were deployed for 24 hours. Samples were collected by pouring the contents of the trap through a 0.106 mm sieve, washing into a sample jar, and preserving in 70% isopropanol. Samples were returned to the laboratory and identified. Most samplings consisted of seven replicates, but some traps were knocked over or lost due to human impact or weather.

In order to qualitatively assess the insects being made available to juvenile salmon as prey, we also collected one long neuston tow per sampling event on the water surface along the shoreline. A floating net (16" x 8", 130 µm) was towed by snorkeling parallel to the shoreline during high tide. When combined with the insect trap sampling this provided an overall comparison of the insect assemblages in the riparian zone and along the shoreline, with that occurring on the surface of the water where they were available to juvenile salmon.

Statistical Analysis
Data was entered in Microsoft Excel and analyzed using S-plus (univariate statistics) and Primer (multivariate statistics) software (Clarke and Warwick 2001). ANOVA tests (alpha = 0.05) were used to analyze log-transformed densities of juvenile Chinook/coho

and chum salmon at different habitat types. Densities of the overall fish community were analyzed with nonmetric multidimensional scaling (NMDS) ordination, in order to uncover patterns in multivariate groupings of the data (Clarke 1993), which is appropriate when analyzing datasets with multiple species compositions. NMDS was used to graphically plot differences in species assemblages onto two dimensional charts in multidimensional space based on a Bray-Curtis similarity matrix, thus the axes have no scale. Densities were log-transformed for ordination, and placed into major species groupings of Chinook/coho salmon, chum salmon, crabs, pile perch, shiner perch, striped seaperch, larval fish, tubesnout, and other nearshore fish.

After plotting the data using ordination, ANOSIM analysis was used to test for significant differences in overall fish communities, and SIMPER analysis was used to test the contribution of individual species in the separation between groups of samples (Valesini et al. 2004). ANOSIM is equivalent to multivariate analysis, as an ANOVA is to univariate analysis, testing for differences between factors such as species composition at habitat types. The results give two test statistics: (1) an R-value scaled between -1 and +1, with a value of zero representing no difference among a set of samples, and the closer the value to 1 the greater the biological importance of the differences, and (2) a p-value similar to an ANOVA, with values of $p < 0.05$ indicating significance. When ANOSIM reveals significant differences between factors, SIMPER analysis can be used to uncover which species are responsible for the differences. SIMPER generates a ranking of the percent contribution of the species that most contribute to the significant differences between factors.

Results

Environmental Parameters
Tidal elevations during snorkel surveys differed about 8 ft. between high and low tide transects, averaging +8.3' MLLW for high tide transects and +0.4' for low tide transects. Average salinity and temperature ranges varied little with water depth, averaging 25.6 psu and 12.0 °C at the surface, and 26.6 psu and 11.6 °C at the bottom. Water clarity was generally better at high tide and earlier in the springtime, as measured by horizontal secchi readings (Fig. 6). The seawall sites were deeper and had a steeper slope than the rip-rap sites, as illustrated by depth gradients between the shallow and deep snorkel transects (Table 1).

Fish
A total of 192 snorkel transects were sampled on 12 days of sampling. Twenty-three species of fish and crabs were counted during snorkel surveys (Table 2). Identification of salmon species while snorkeling was sometimes difficult because of water turbidity and short viewing time. Therefore, salmonids were sometimes designated as either "unknown juvenile salmonids" or grouped into one category of "Chinook/coho". Two fish species made up 95% of the overall observed fish numbers: shiner perch dominated (82%), followed by juvenile chum salmon (13%). Crab observations were dominated by kelp crabs and red rock crabs.

Juvenile chum salmon were the most abundant fish species in April (Figs. 7, 8). Shiner perch dominated counts in May and through the rest of the sampling (Fig. 7). Pile perch and striped seaperch were scarce in April, but were relatively abundant by May. Larval fish were most abundant at the end of June and in July, followed by high numbers of other nearshore fish (the only occurrences of sand lance and herring) on the last sampling date on 8 July. Crabs were consistently observed in low abundances.

Chum were the most abundant juvenile salmonid: they peaked in April, but had largely disappeared by the end of May (Fig. 8). Chinook fry were relatively abundant on 22 April, and a peak of Chinook smolts and the Chinook/Coho category occurred on 27 May. Peaks were undoubtedly somewhat related to hatchery releases, as 3.4 million subyearling Chinook were released from the WDFW hatchery (Soos Creek) during 21 May – 2 June. Chinook smolts continued to be the dominant salmonid species through the end of the sampling. Steelhead trout also occurred in May at low abundances (5 total counted).

Overall fish assemblages differed between shallow and deep transects (Fig. 9). Juvenile salmonids, striped seaperch, pile perch, larval fish, and crabs were more abundant at the shallow transects, while other nearshore fish and shiner perch were more abundant at the deep transects. Similarly, juvenile salmonids were more abundant in high tide transects and shiner perch were more abundant in low tide transects, although this difference was not as great as in the shallow vs. deep transects (Fig. 9).

For juvenile salmonid densities, Chinook/coho and chum had significantly greater densities in shallow than in deep water, based on ANOVA ($p < 0.01$ for both; Fig. 10). Although salmonid densities were also higher at high tide transects vs. low tide transects, this difference was not statistically significant (Fig. 10).

Overall average fish densities were highest at the deep rip-rap transects, due to large numbers of shiner perch observed there (Fig. 11). Juvenile salmonids had higher densities at the shallow transects for each strata, mainly due to high chum densities at the shallow seawall transects and a combination of high Chinook and chum densities at the shallow rip-rap transects (Fig. 12).

Multivariate analysis of the fish community, with a 2-d stress of 0.17, proved to be a "useful" representation of the data according to statistical guidelines (stress less than 0.2 considered useful; Clarke 1993). The ordination plot showed the shallow and deep transects clustering separate from each other (Fig. 13). A one-way ANOSIM was used to show the degree to which the shallow and deep transects at seawall and rip-rap sites differed. R-values were high and significant between the shallow and deep transects at both rip-rap and seawall (0.375 and 0.239, respectively; a higher R-value indicates greater biological importance; Table 3). R-values were low between the seawall and rip-rap sites, indicating that they had similar species compositions. SIMPER analysis showed that the main species driving the significant differences were higher densities of shiner perch at the deep sites, and higher densities of juvenile salmonids, striped seaperch, pile perch, larval fish, and crabs at the shallow sites (Table 3).

Although this sampling occurred before construction, there were some differences between the reference and restoration stretches of shoreline at the shallow water transects. At the restoration stretches, there were more total fish than at the reference stretches, mostly due to shiner perch (Fig. 14). Juvenile salmonids were more abundant at the seawall restoration stretch than the reference stretch, mostly due to high numbers of chum (Fig. 15). For other taxa/groups, the restoration and reference sites were much more similar (i.e., crabs, larval fish, striped seaperch, pile perch), and the deep sites were more consistent than the shallow sites in fish compositions between the restoration and reference sites. Red rock crabs were more abundant at both seawall shallow sites, and kelp crabs were more abundant at both rip-rap shallow sites (Fig. 16). Overall taxa richness was similar at seawall and rip-rap sites, with an overall taxa richness of 18 for rip-rap sites and 19 for seawall sites. At both the seawall and rip-rap sites, there was a difference between shallow and deep transects, with higher taxa richness at shallow locations; this difference was more pronounced at the seawall site (Fig. 17).

Water column position and behavior varied by species (Table 4). For salmonids, water column position was mostly middle and surface for Chinook, and surface for chum. Most other fishes occurred at middle to bottom depths, and crabs were noted off bottom only if they were climbing on a vertical surface such as a piling or the seawall. The most common behaviors were swimming away, schooling, and unaffected, although there were some occurrences of feeding for juvenile salmonids.

Percentage of observations of juvenile salmonids in categories of water column position and behavior were fairly consistent between strata, with a few variations (Table 5). At the rip-rap shallow sites juvenile Chinook and coho occurred more at the surface than the middle, whereas the converse was true at the seawall shallow sites. This may be because of the greater depths at the seawall sites. Similarly, the only observations of chum in the middle of the water column were at seawall shallow sites, otherwise they were all at the surface. Juvenile Chinook and coho were also observed feeding more often at the shallow rip-rap sites than at seawall sites.

Epibenthic Invertebrates
Overall species composition and densities of epibenthic invertebrates was similar among the sampling sites (Fig. 18). Two taxa, the gammarid amphipod *Paracalliopiella pratti* (Fig. 19) and a combination of barnacle life history stages, made up more than 75% of invertebrate numbers at each site. Harpacticoid copepods accounted for the majority of the remaining densities (Fig. 20). The two rip-rap sites had more barnacle nauplii than the seawall sites, and the seawall reference site had more *P. pratti* than the restoration site. Overall, rip-rap sites had greater taxa richness than the seawall sites (Table 6). The rip-rap sites had several more species of amphipods and isopods (Fig. 21), harpacticoid copepods (Fig. 22), and "other" taxa (Fig. 23) as compared to the seawall sites. Total abundances of copepods and "other" taxa were also higher at the rip-rap sites.

Insects

Species composition of insects from fallout traps was similar among the seawall and rip-rap sites (Fig. 24). The majority of insects at these sites consisted of dipteran insects (flies, mostly consisting of midges in the family Chironomidae; Fig. 25), followed by collembola (springtails; Fig. 26), and acarina (mites). Densities of dipterans and total insects were higher at the two restoration sites as compared to the reference sites. The seawall sites had higher taxa richness than the rip-rap sites, mostly due to rare occurrences of hymenoptera (wasps) and coleoptera (beetles) (Fig. 24, Table 7). The backshore riparian site had the highest total densities and taxa richness (Fig. 24, Table 7). This site also differed from the seawall and rip-rap sites in having a lower proportion of dipterans, and higher proportions of collembola, acarina, heteroptera, psocoptera, and hymenoptera.

The qualitative neuston samples had an insect assemblage composition similar to the fallout traps, with dipteran insects the most abundant taxon (Fig. 27). Minor differences included proportionally more heteroptera, hymenoptera, and coleoptera in the neuston and more diptera and collembola in the insect traps. The neuston tows also contained some aquatic invertebrates that were sampled in the epibenthic sampling, such as the amphipod *Paracalliopiella pratti* and harpacticoid copepods.

Discussion and Conclusions

<u>Fish</u>
As in previous studies of City of Seattle shorelines, juvenile salmon in this study were abundant in shallow water habitats (Toft et al. 2004), and were observed feeding. In addition, the restoration sites appeared to have more fish than the reference areas, especially at the seawall stretch of shoreline. The reason may be that the restoration sites occur in areas of slight indentations in the shoreline, and this may cause fish to aggregate there. It is also possible that the large overwater structure adjacent to the reference seawall site may have influenced the fish distribution. Irregardless, benefits arising from created habitat in the Sculpture Park design should be available for juvenile salmon, due to their high numbers in shallow water along the restoration stretch of shoreline. Benefits should occur for other species of nearshore fish as well due to the variety of fishes present. Intertidal beaches in Puget Sound also provide spawning habitat for Pacific sand lance and surf smelt (Rice 2006); it is possible that intertidal beach restoration could further benefit these species. Because juvenile salmon and other fish already occur at the sites, post-construction monitoring should particularly note any changes in fish densities, assemblage compositions, and behavior.

Shoreline armoring such as the seawall and rip-rap at the study site steepen the intertidal and truncate the shallow water zone used by juvenile salmon and their prey invertebrates. At the seawall sites, which had the steepest gradients, juvenile salmon tended to be in deeper water, and were less often observed feeding. Presumably, the low gradient habitats planned for the site will provide additional intertidal habitat beyond that which exists presently.

In creating intertidal habitat for juvenile salmon, concern is sometimes expressed about the new habitat attracting potential predators of the salmon. In this study we rarely observed potential fish predators such as sculpins, steelhead trout, and lingcod. However, predator monitoring should be taken into account in post construction studies of the sites. It is also unknown if prey is limiting for populations of juvenile Chinook salmon in this area. There is likely some overlap with feeding types among the most numerous fish species; shiner perch are omnivorous, eating mostly small crustaceans and algae (Bane and Robinson 1970), and chum are mainly epibenthic feeders at smaller sizes (<50-60 mm forklength), moving to planktonic prey items as they increase in size (Simenstad et al. 1982). Habitat enhancements will most likely increase availability of prey items for all of these nearshore species, and specifically for juvenile Chinook which feed primarily on insects and epibenthic crustaceans (Simenstad et al. 1982, Brennan et al. 2004). Future research may seek to incorporate feeding studies in order to illustrate diet preferences and overlap among fish species.

Epibenthic Invertebrates
The dominant epibenthic invertebrate found in this study, the gammarid amphipod *Paracalliopiella pratti*, is usually associated with submerged plants and algae or organic debris (Bousfield and Hendrycks 1997). At the Olympic Sculpture Park site, these amphipods were probably associated with algae produced in the lower intertidal portions of the seawall and rip-rap habitats. This species and other species in the family Calliopiidae have also been found to be abundant in similar hard substrata elsewhere in Elliott Bay, such as along rip-rap shorelines at Terminal 5 (Taylor et al., unpublished report to Port of Seattle). The second most abundant taxon in epibenthic samples were various stages of barnacles, which were clearly associated with, and abundant on the seawall and rip-rap substrata. The neuston samples also contained epibenthic invertebrates such as *P. pratti* and harpacticoid copepods, which may have been suspended in the water column by wave action at the face of the seawall and rip-rap. Because the habitat created in the Sculpture Park project will consist of lower gradient, softer sediments, post-construction monitoring should take this into account. These new habitats may develop higher taxa richness, or higher proportions of rare and mobile taxa than at seawall and rip-rap sites (Chapman 2003). Other types of juvenile salmon prey taxa such as benthic amphipods (e.g., *Corophium* spp.), epibenthic harpacticoid copepods (e.g., *Harpacticus* spp., *Tisbe* spp.) and polychaete worms may be more abundant in the new habitat. Sampling methods specific to these types of organisms may be considered, such as benthic core sampling, in addition to epibenthic pump samples.

Insects
Our finding of highest taxa richness and densities of insects at the backshore riparian site suggests that the insects are mainly associated with vegetation. The qualitative neuston samples also illustrate that a spectrum of insects similar to that found in the shore-based trap samples is available as juvenile salmon prey. Therefore, it seems likely that plantings of vegetation associated with the Sculpture Park will increase input of insects into the nearshore aquatic environment. This is supported by two recent studies, which have shown supralittoral insect communities to be significantly reduced where shoreline

vegetation has been removed in association with armoring (Romanuk and Levings 2003, Sobocinski 2003).

Post-Construction Monitoring

We recommend periodic post-construction monitoring (e.g. 1, 3, 5, 7, 10 years after construction), beginning spring 2007 in order to assess ecological development of the site. Maintaining the paired-sample design and identical methodology used in this study will increase the likelihood of detecting changes associated with the new habitat. In addition to the attributes measured in the pre-construction study, the following additional sampling methods should be considered in post-construction monitoring:

- Presence and behavior of potential juvenile salmon predators.
- Capture of juvenile salmon using enclosure nets, in order to obtain site-specific densities and food habits.
- Invertebrate sampling tailored to the new lower-gradient habitats (e.g., cores).
- Quantitative neuston sampling (i.e., transects of standard length).

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Figure 1. Aerial photograph of the Olympic Sculpture Park site before construction, showing sampling locations.

Figure 2. Artist's rendition of the completed Olympic Sculpture Park, showing sampling locations.

Figure 3. Snorkel surveys being conducted at onshore and offshore transects.

Figure 4. Epibenthic pump sampling of aquatic invertebrates on rip-rap.

Figure 5. Insect traps deployed on the seawall.
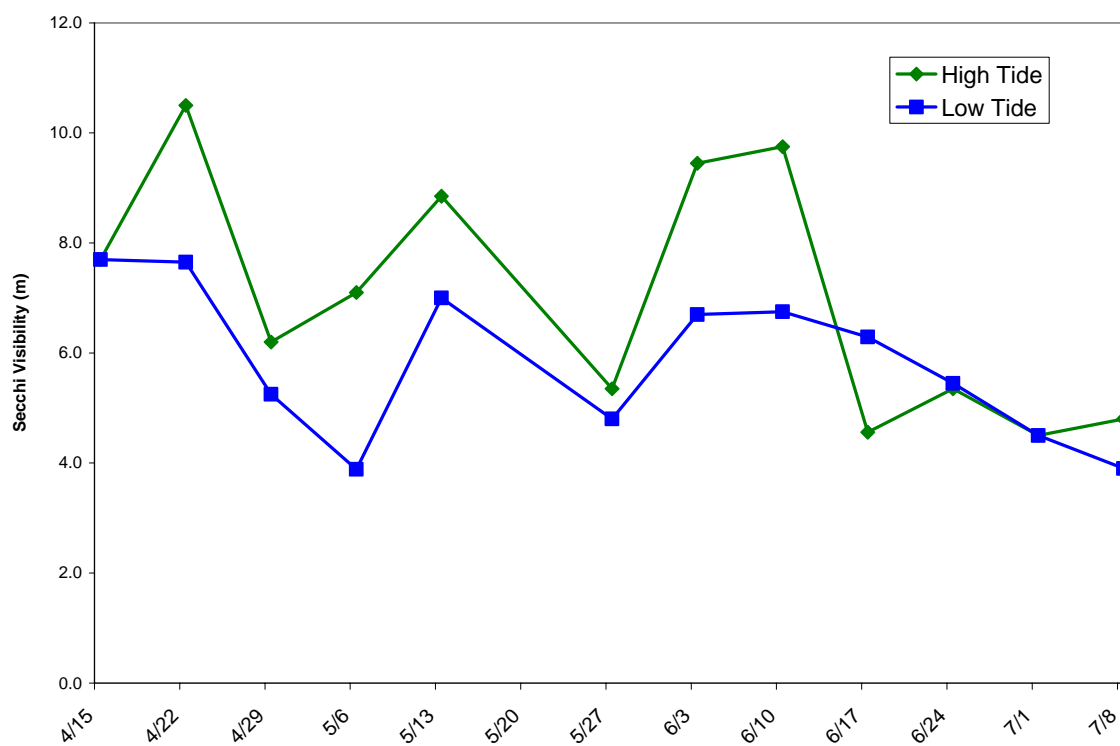

Figure 6. Average horizontal secchi measurements of underwater visibility on each snorkel survey date, at both high and low tide.
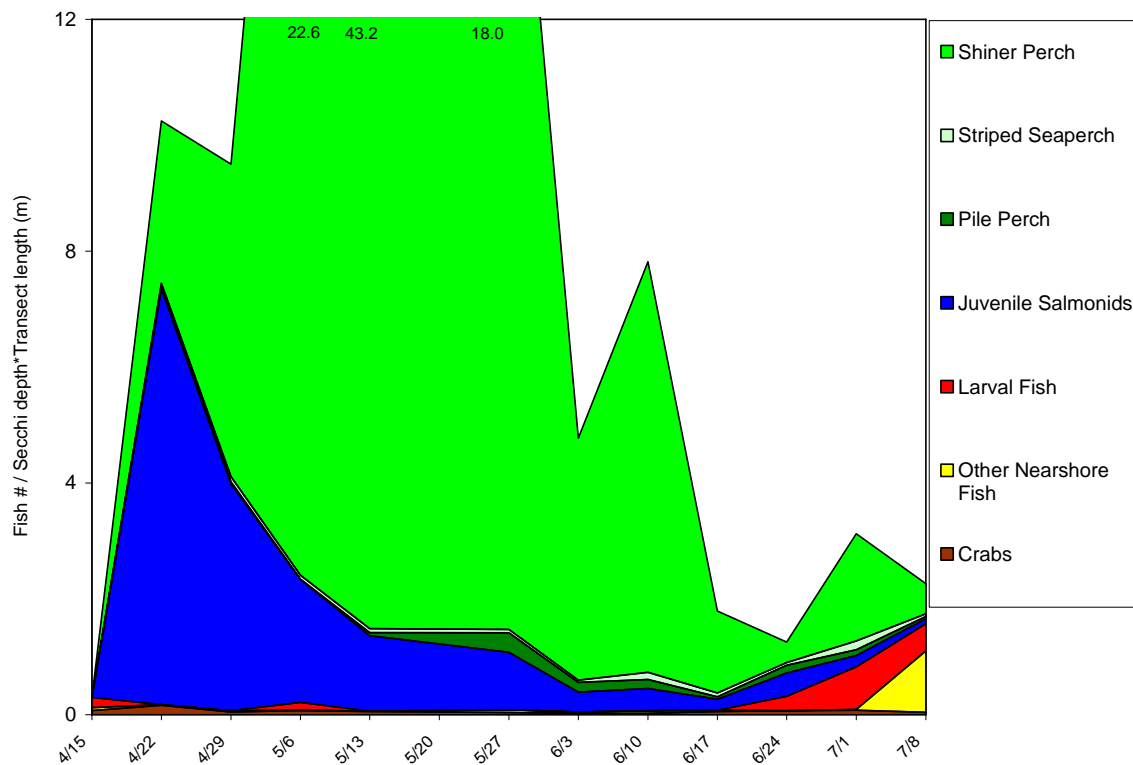
Figure 7. Overall fish densities recorded from snorkeling transects on each sampling date (no sampling occurred on 5/20).
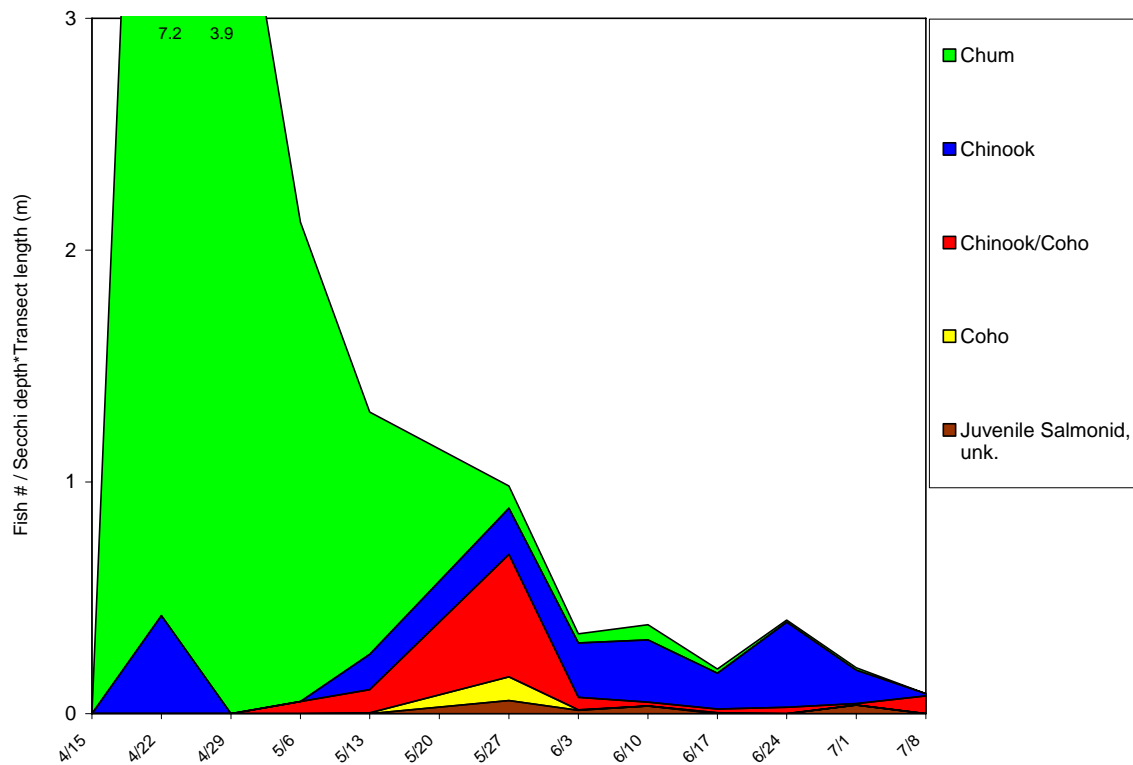
Figure 8. Densities of juvenile salmonids recorded from snorkeling transects on each sampling date (no sampling occurred on 5/20).
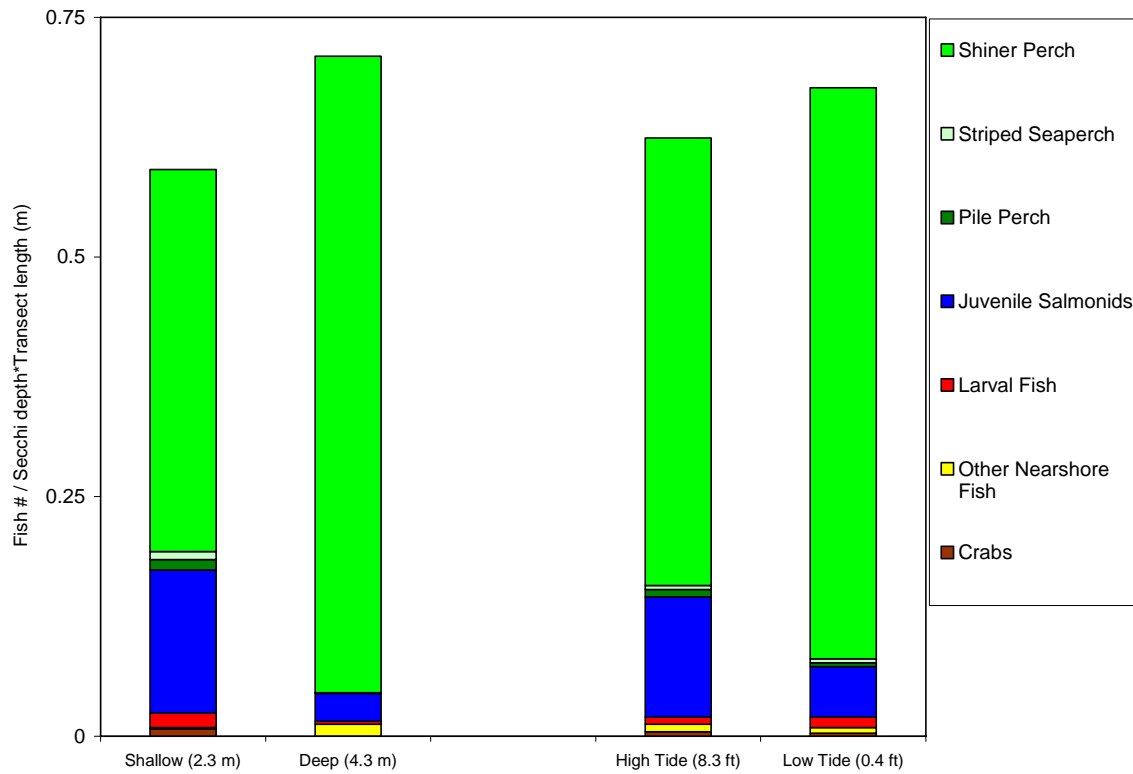
Figure 9. Average overall fish densities at shallow/deep and high/low tide snorkeling transects.
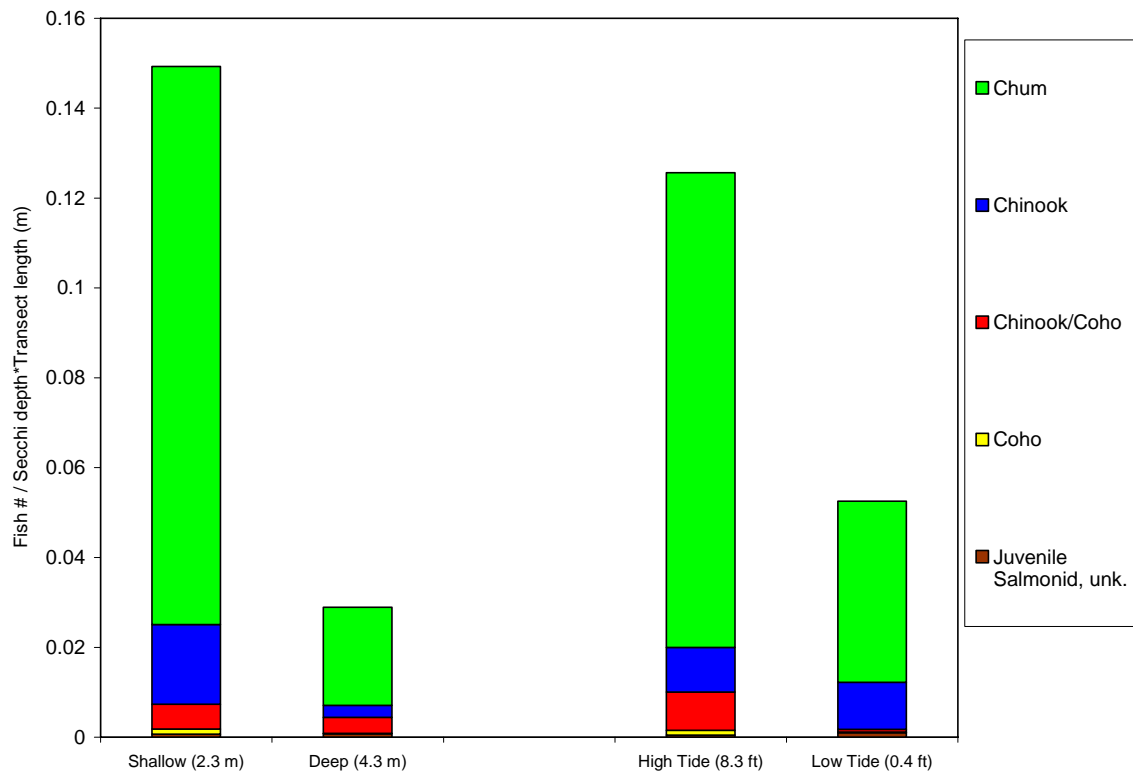
Figure 10. Average densities of juvenile salmonids at shallow/deep and high/low tide snorkeling transects.
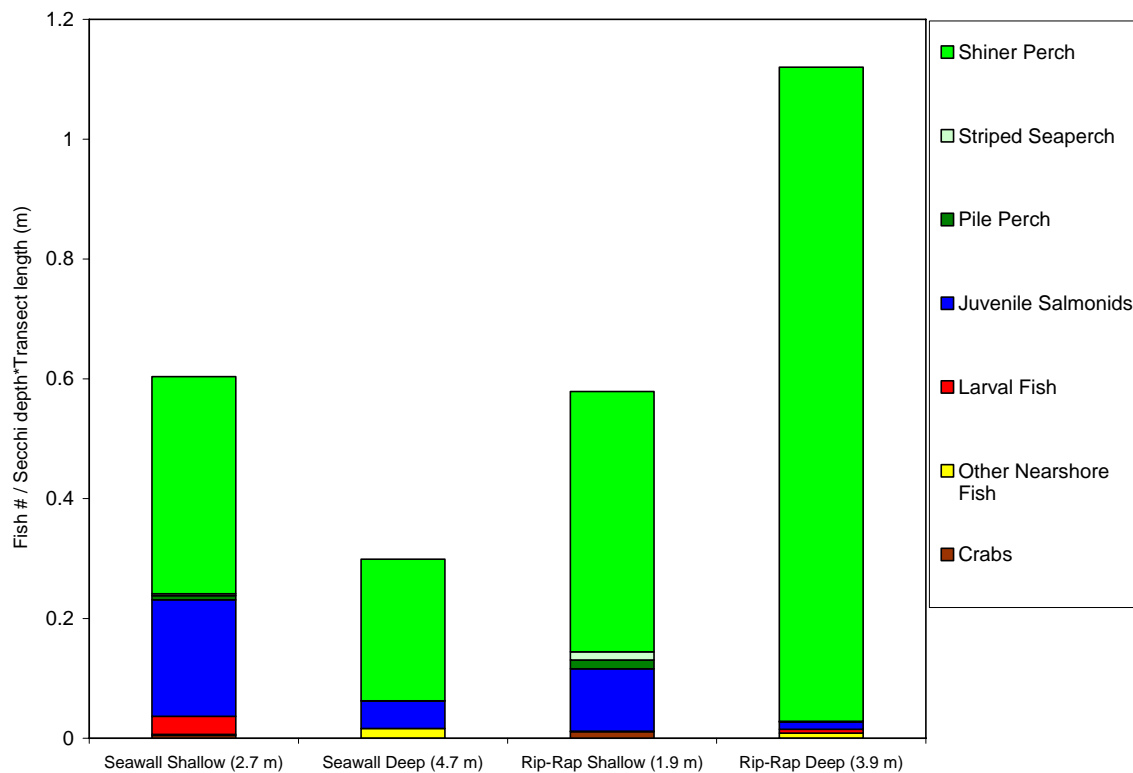
Figure 11. Average densities of fish at seawall and rip-rap snorkeling transects.
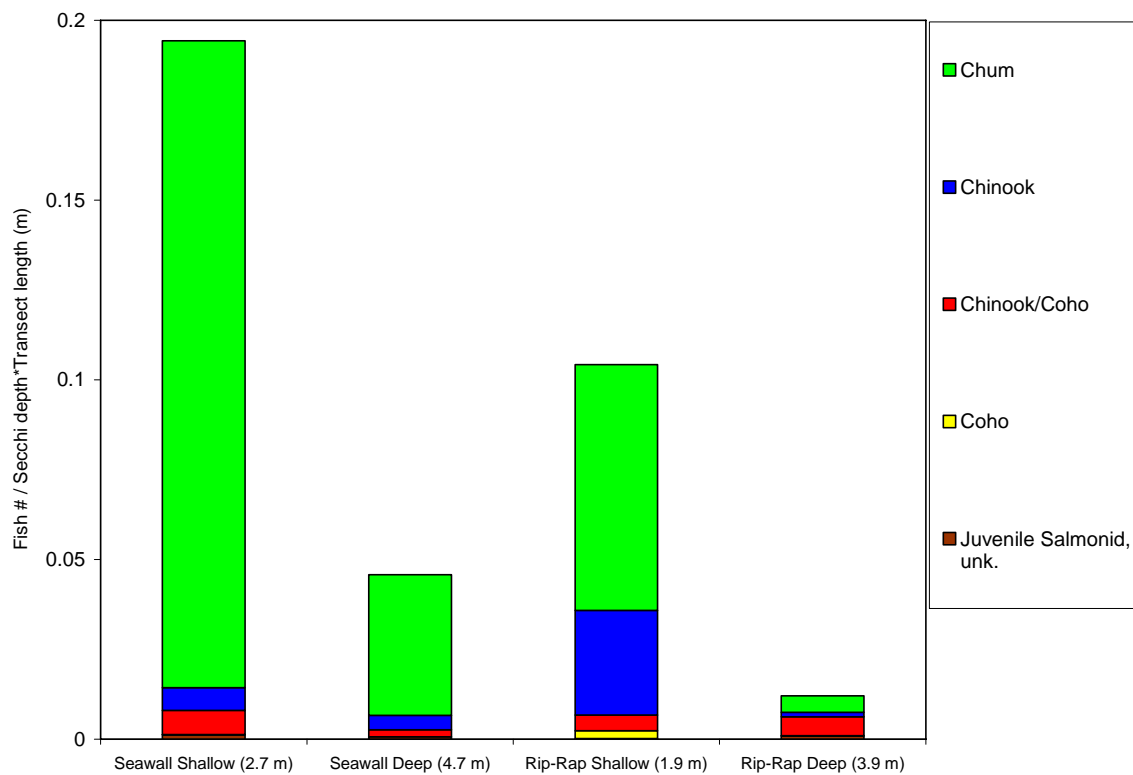
Figure 12. Average densities of juvenile salmonids at seawall and rip-rap snorkeling transects.
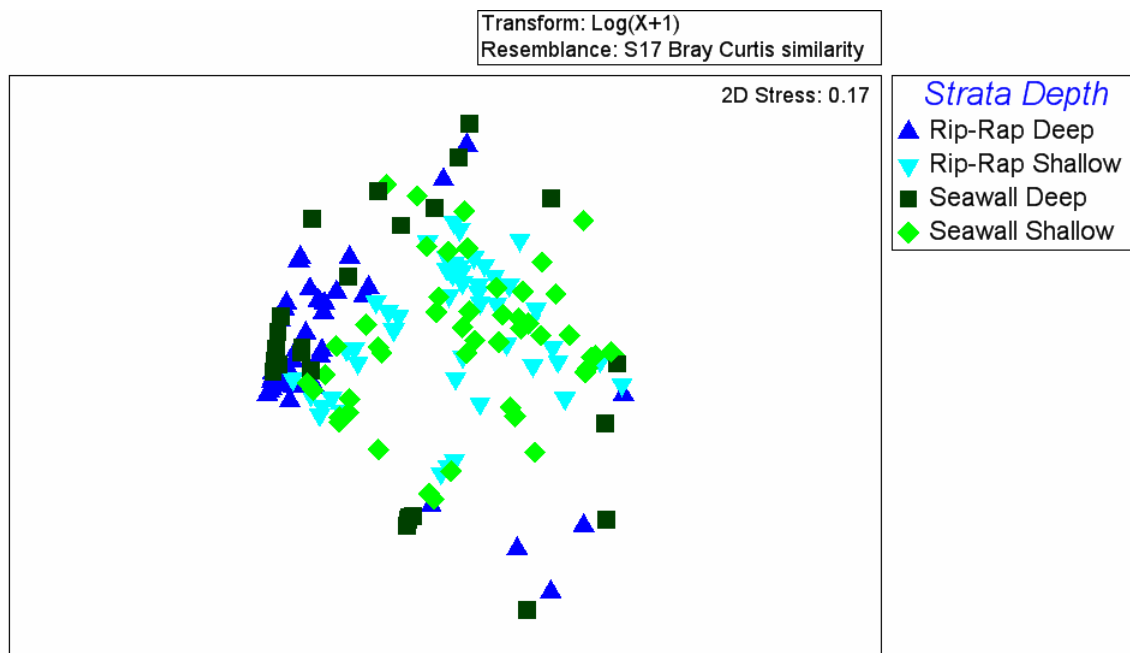
Figure 13. NMDS ordination on overall fish densities, plotted for four transect types.
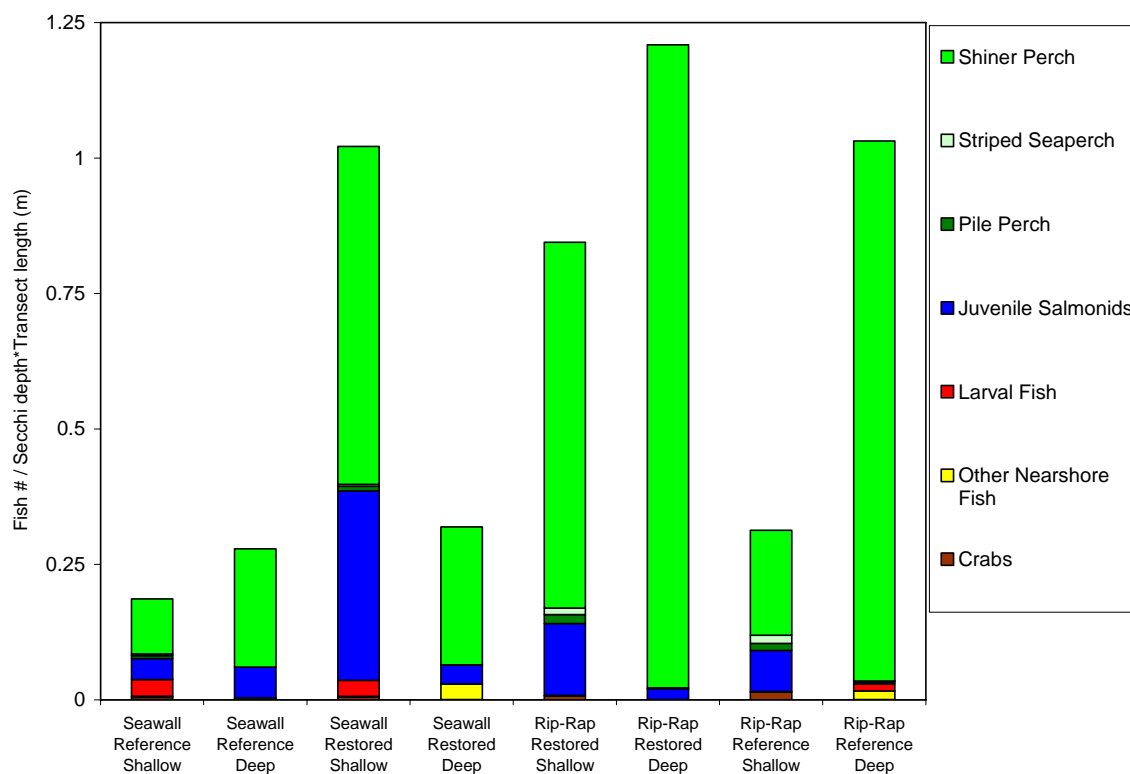
Figure 14. Overall average fish densities at seawall and rip-rap restoration and reference snorkeling transects.
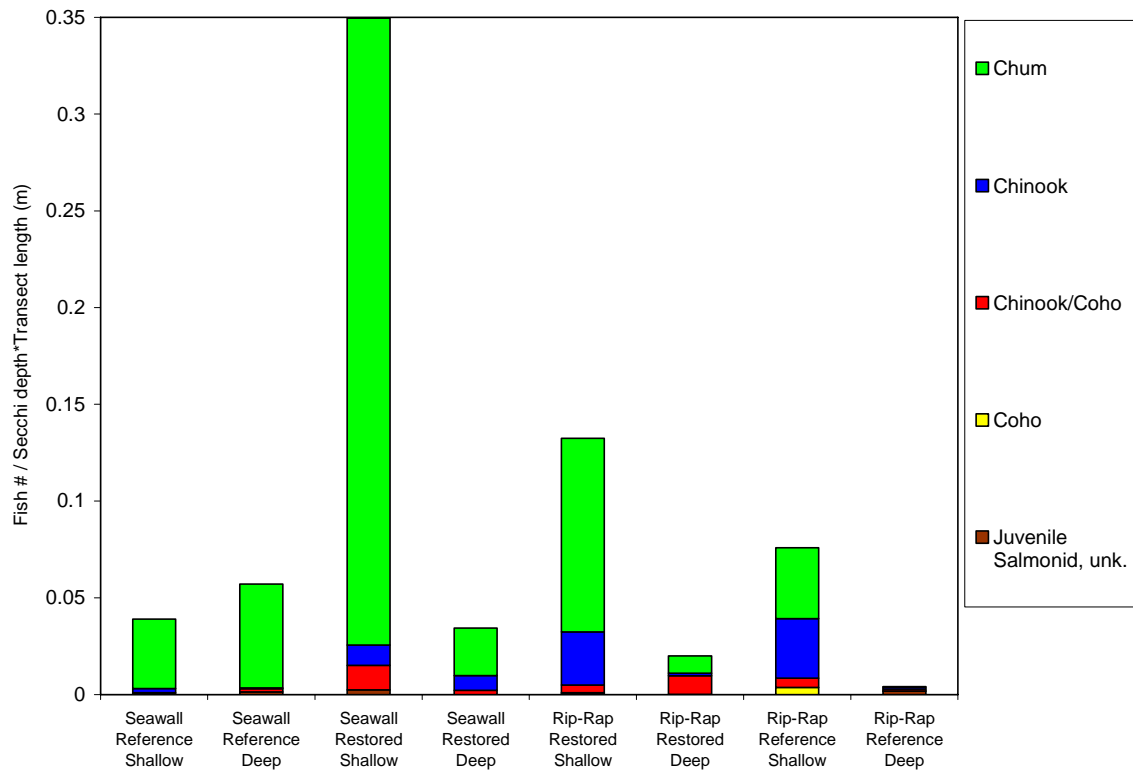
Figure 15. Average densities of juvenile salmonids at seawall and rip-rap restoration and reference snorkeling transects.
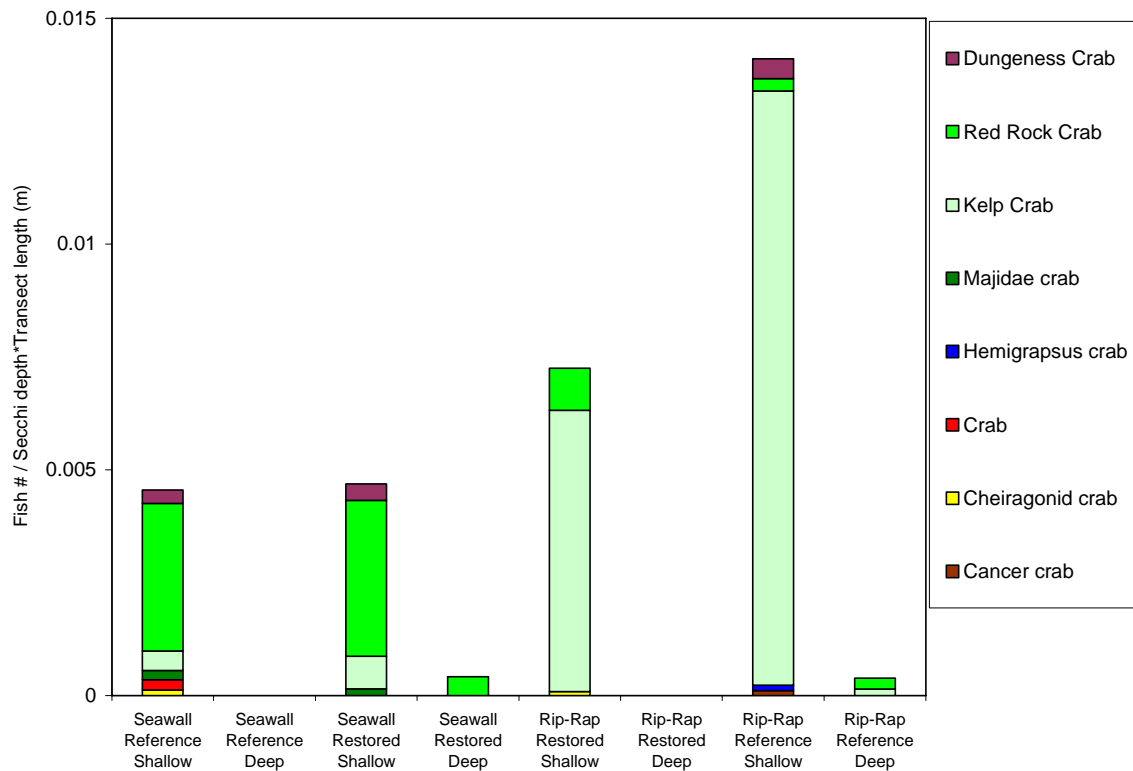
Figure 16. Average densities of crabs at seawall and rip-rap restoration and reference snorkeling transects.
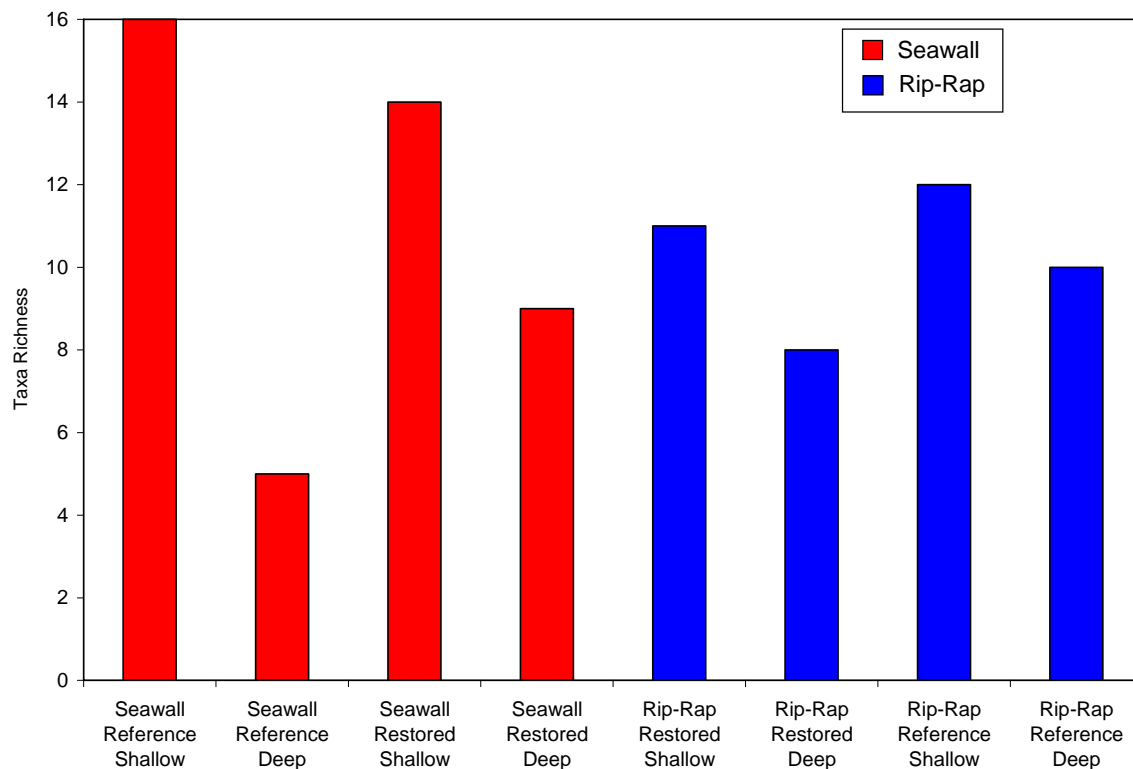
Figure 17. Taxa Richness at seawall and rip-rap restoration and reference snorkeling transects.
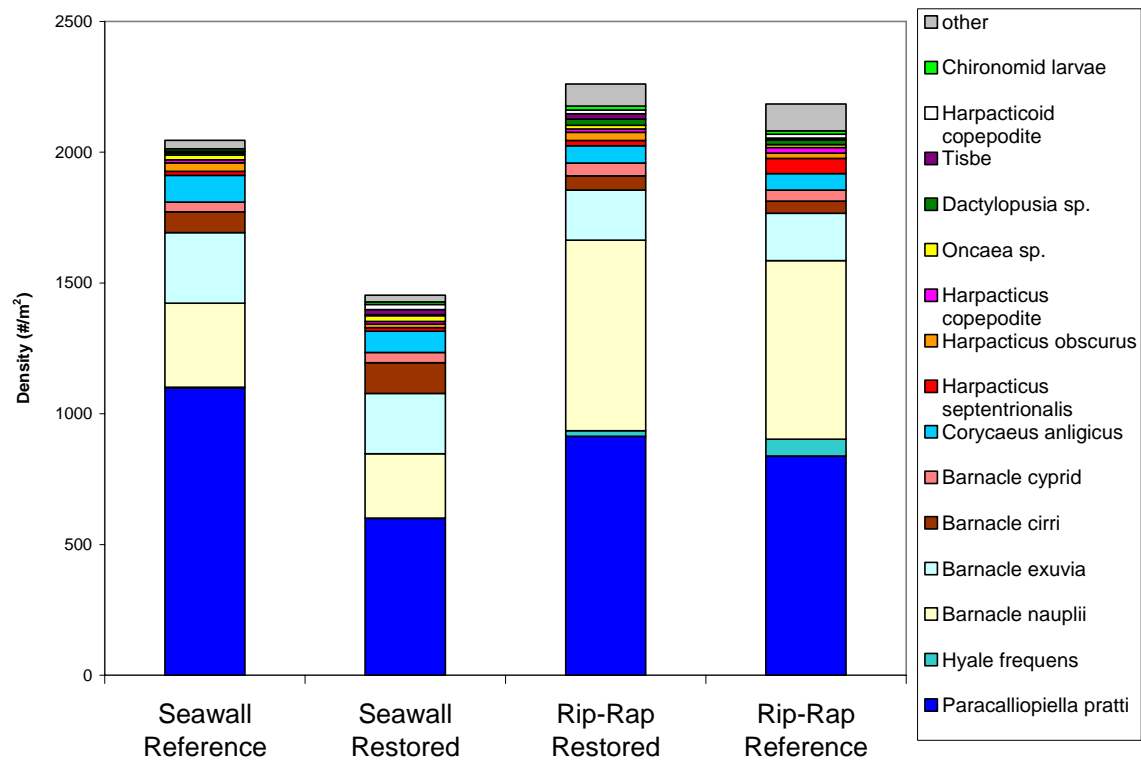
Figure 18. Average densities of epibenthic invertebrates at seawall and rip-rap restoration and reference sites.

Figure 19. The gammarid amphipod *Paracalliopiella pratti*.

Figure 20. The harpacticoid copepod *Harpacticus uniremis*.
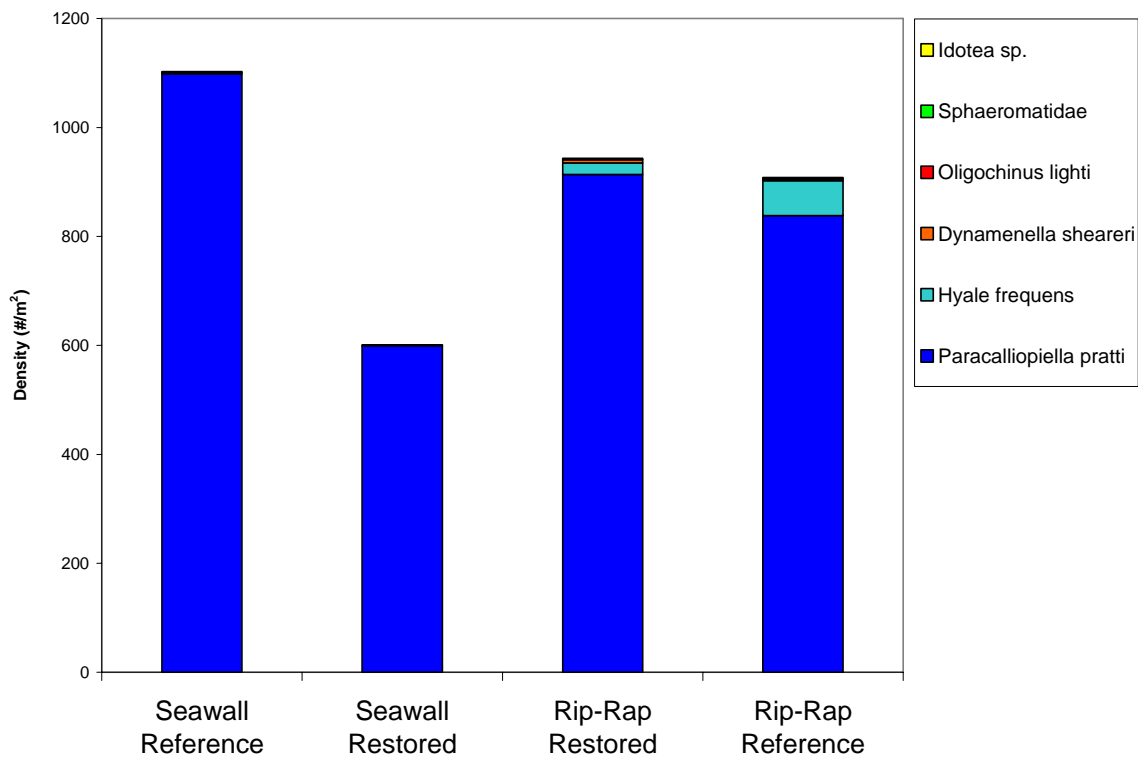
Figure 21. Average densities of amphipods and isopods at seawall and rip-rap restoration and reference sites.
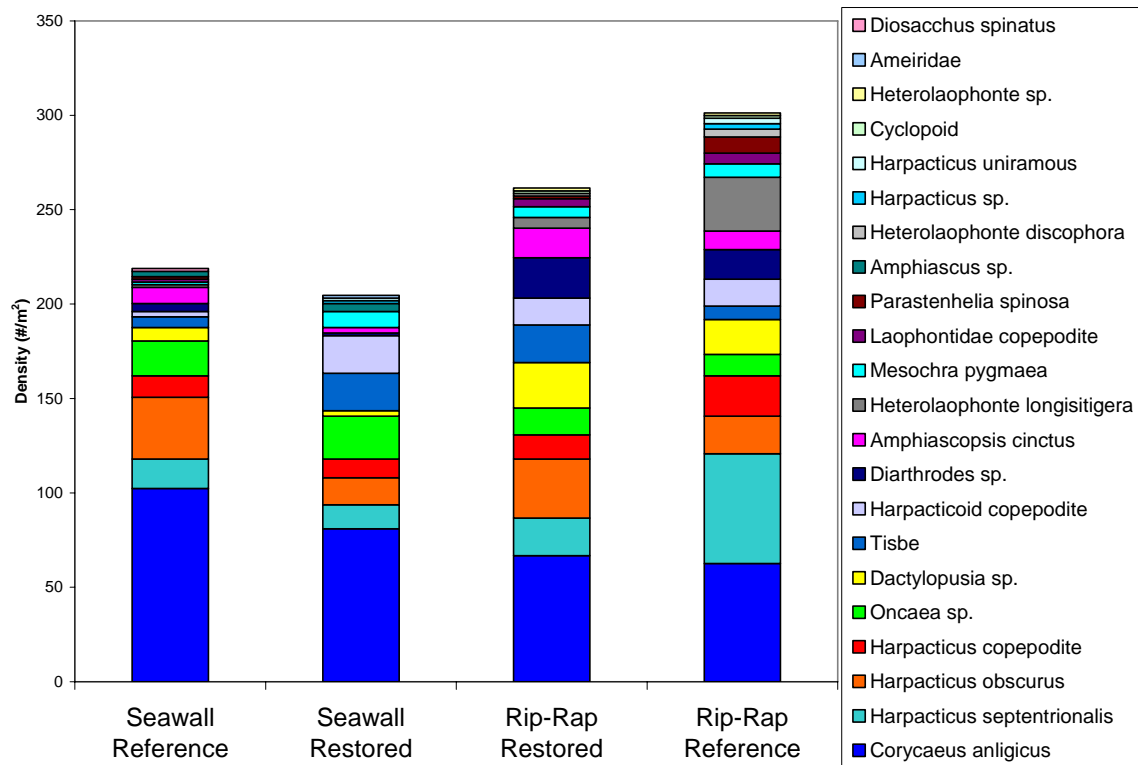
Figure 22. Average densities of harpacticoid and cyclopoid copepods at seawall and rip-rap restoration and reference sites.
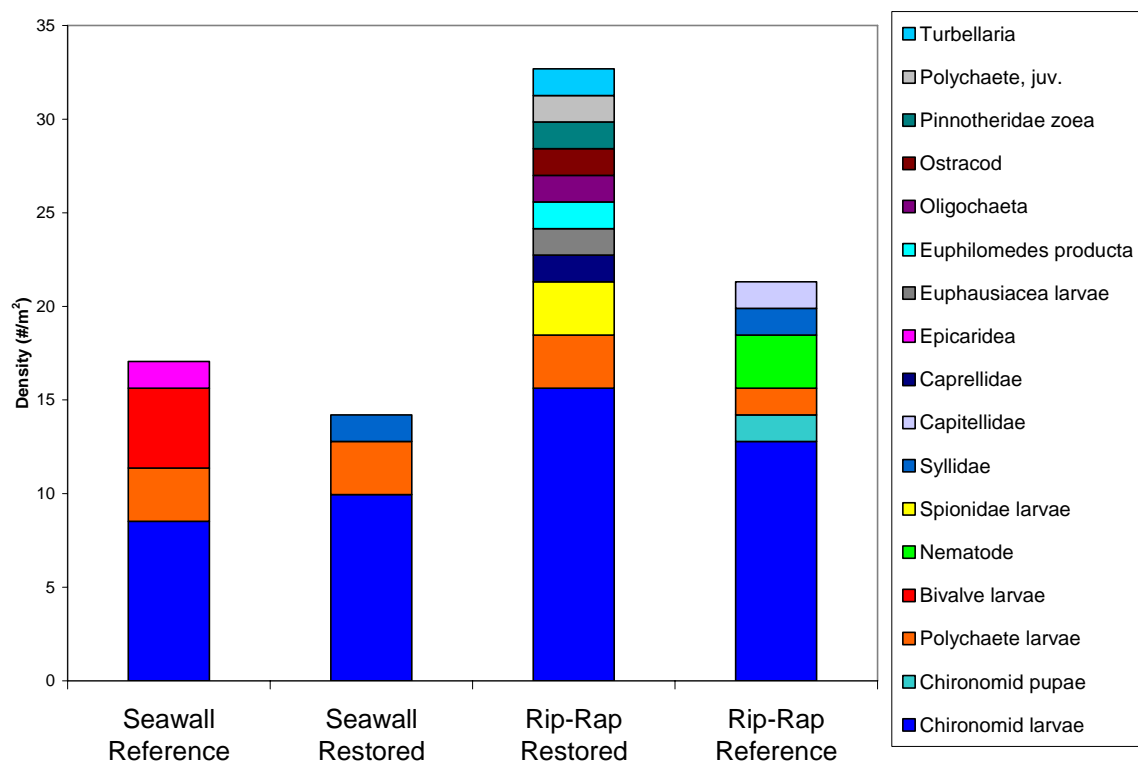
Figure 23. Average densities of other epibenthic taxa at seawall and rip-rap restoration and reference sites.
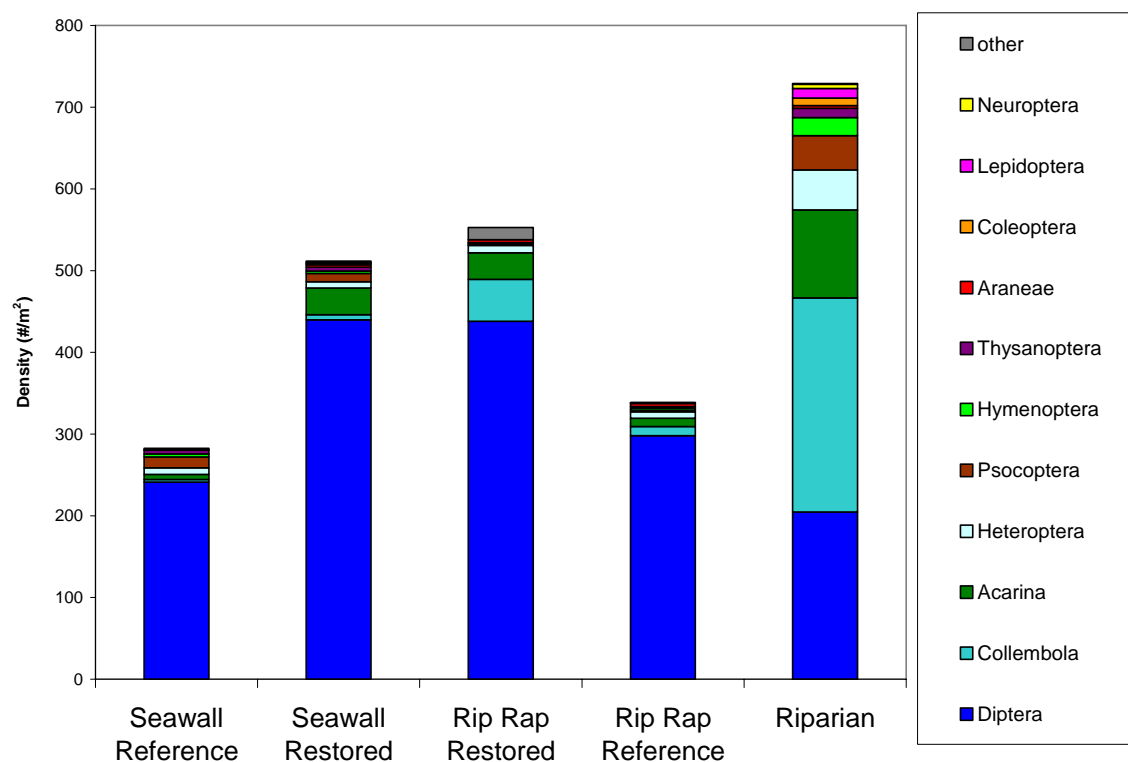
Figure 24. Average densities of insects at seawall and rip-rap restoration and reference sites.

Figure 25. Adult midge (Order Diptera, family Chironomidae).

Figure 26. Springtail (Order Collembola).
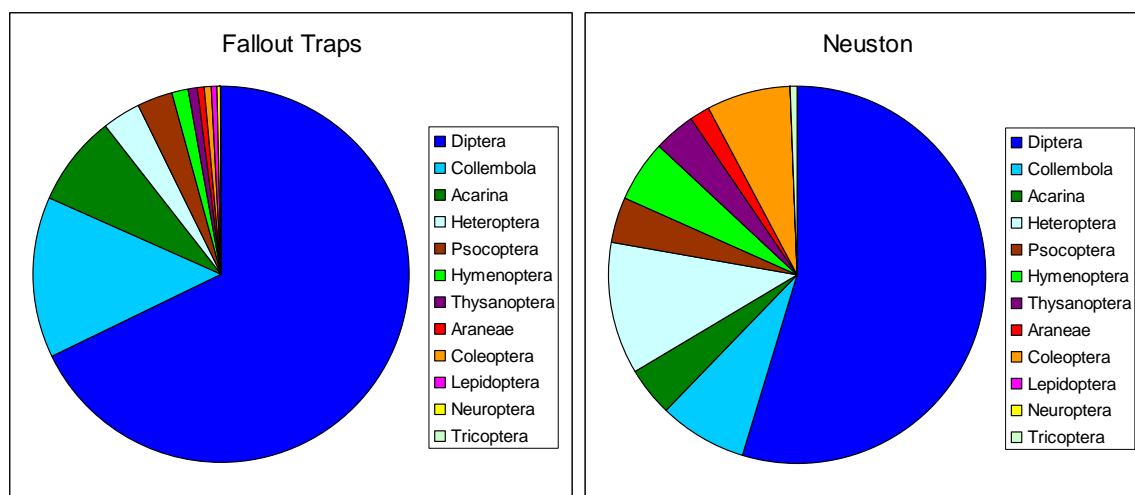
Figure 27. Total insect assemblage composition from fallout traps and neuston tows.

Table 1. Average water depths (m) from snorkel surveys, for high (avg +8.3' MLLW) and low (avg +0.4' MLLW) tides, and shallow (3-m from shore) and deep (10-m from shore) transects.

Rip-Rap				Seawall			
High Tide		Low Tide		High Tide		Low Tide	
Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
2.3	4.2	1.6	3.6	3.5	5.5	1.8	4.0

Table 2. Average length estimates and total counts of fish and crabs from snorkel surveys. Length estimates of fish are based on total length, and crab lengths are carapace width.

Common Name	Scientific Name	Average Length (cm)	Total Number of Counted Fish
Bay Pipe Fish	*Syngnathus griseolineatus*	13.8	2
Cheiragonidae crab	Cheiragonidae	7.5	2
Chinook	*Oncorhynchus tshawytscha*	10.4	975
Chinook/Coho	*Oncorhynchus tshawytscha/kisutch*	10.8	407
Coho	*Oncorhynchus kisutch*	12.5	44
Chum	*Oncorhynchus keta*	6.1	7,993
Juvenile Salmonid, unk.	*Oncorhynchus* spp.	9.9	58
Dungeness Crab	*Cancer magister*	13.4	11
Gunnel	Pholidae	31.3	1
Hemigrapsus crab	Hemigrapsus spp.	3.8	1
Herring	*Clupea harengus pallasi*	13.8	100
Kelp Crab	*Pugettia* spp.	8.3	272
Kelp Perch	*Brachyistius frenatus*	10.3	16
Lamprey	Petromyzonidae	13.8	1
Larval Fish	-	3.8	661
Lingcod	*Ophiodon elongatus*	82.9	3
Majidae crab	Majidae	5.4	3
Pacific Sand Lance	*Ammodytes hexapterus*	8.8	250
Perch, unk.	Embiotocidae	15.0	41
Pile Perch	*Rhacochilus vacca*	13.5	525
Ratfish	*Hydrolagus colliei*	101.3	1
Red Rock Crab	*Cancer productus*	12.8	96
Sculpin	Cottidae	8.8	1
Shiner Perch	*Cymatogaster aggregata*	8.5	50,461
Steelhead Trout	*Salmo gairdneri*	17.5	5
Striped Seaperch	*Embiotoca lateralis*	14.7	370
Tubesnout	*Aulorhynchus flavidus*	17.1	49

Table 3. Summary statistics from multivariate analysis of fish densities. ANOSIM is equivalent to a univariate ANOVA, and SIMPER analyzes the species that have the largest contributions to statistical differences.

1-way ANOSIM on site

	R-value	p value
Rip-Rap, Deep vs Shallow	0.375	< 0.001
Seawall, Deep vs Shallow	0.239	< 0.001
Shallow, Rip-Rap vs Seawall	0.048	1
Deep, Rip-Rap vs Seawall	0.128	< 0.009

SIMPER Analysis

	Average log-transformed densities		
	Rip-Rap Deep	Rip-Rap Shallow	% contribution
Shiner Perch	0.63	0.22	67.5
Chinook/coho	0.01	0.03	9.5
Chum	0.01	0.06	8
Striped Seaperch	0.00	0.01	4.2
Crabs	0.00	0.01	3.7

	Seawall Deep	Seawall Shallow	% contribution
Shiner Perch	0.29	0.19	45.3
Chum	0.06	0.11	20.7
Chinook/coho	0.01	0.01	9
Larval fish	0.00	0.03	5.8
Pile Perch	0.00	0.01	5.2
Crabs	0.00	0.00	4.9

Table 4. Number of observations of fish and crabs for water column position and behavior categories.

Fish Species	Water Column Position			Behavior						
	Bottom	Middle	Surface	Feeding	Fleeing	Injured	Mating	Schooling	Swam Away	Unaffected
Bay Pipe Fish		1	1							2
Cheiragonid crab	1	1								2
Chinook	1	45	54	32				13	46	9
Chinook/Coho		18	9	4	1			10	12	
Coho		7	3	2				3	5	
Chum		5	66	15	1			42	11	2
Juvenile Salmonid, unk.		3	6					3	6	
Dungeness Crab	6	2								8
Gunnel	1									1
Hemigrapsus crab	1			1						
Herring		1		1						
Kelp Crab	93	7					1		1	98
Kelp Perch	3	8		1				1	4	5
Lamprey			1							1
Larval Fish	5	3	1	2				6	1	
Lingcod	3								1	2
Majidae crab	2	1								3
Pacific Sand Lance		1						1		
Perch, unk.	22	1						1	9	13
Pile Perch	118	30		9	2			29	49	59
Ratfish	1									1
Red Rock Crab	62	16	1	1			4		1	73
Sculpin	1									1
Shiner Perch	58	90	1	6		3		79	11	50
Steelhead Trout		1	1					1	1	
Striped Seaperch	158	31		20	1			15	54	99
Tubesnout	6							2		4

Table 5. Percentage of observations of juvenile salmonids for water column position and behavior categories.

Fish Species	Site	Water Column Position			Behavior					Total Number of Observations
		Bottom	Middle	Surface	Feeding	Fleeing	Schooling	Swam Away	Unaffected	
Chinook and Coho	Rip-Rap Reference Deep		75%	25%	25%		25%	50%		4
	Rip-Rap Reference Shallow	3%	47%	50%	20%		23%	43%	13%	30
	Rip-Rap Restored Deep		29%	71%	14%		43%	43%		7
	Rip-Rap Restored Shallow		33%	67%	48%		13%	30%	9%	46
	Seawall Reference Deep		50%	50%			50%	50%		4
	Seawall Reference Shallow		73%	27%			13%	87%		15
	Seawall Restored Deep		50%	50%	25%		75%			4
	Seawall Restored Shallow		78%	22%	26%	4%	7%	59%	4%	27
Chum	Rip-Rap Reference Deep			100%				100%		3
	Rip-Rap Reference Shallow			100%	13%		75%		13%	8
	Rip-Rap Restored Deep			100%			50%	50%		2
	Rip-Rap Restored Shallow			100%	32%	4%	50%	11%	4%	28
	Seawall Reference Deep			100%			80%	20%		5
	Seawall Reference Shallow		33%	67%	17%		67%	17%		6
	Seawall Restored Deep			100%			100%			1
	Seawall Restored Shallow		17%	83%	22%		67%	11%		18

Table 6. Taxa richness of epibenthic invertebrates.

Site	Taxa Richness
Seawall Reference	22
Seawall Restored	19
Rip-Rap Restored	28
Rip-Rap Reference	27

Table 7. Taxa richness of insects.

Site	Taxa Richness
Seawall Reference	43
Seawall Restored	50
Rip-Rap Restored	38
Rip-Rap Reference	37
Riparian	69